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Environmental Drivers for Benthic Macroinvertebrate Assemblages and Distributional Patterns in a Plateau River of Bundelkhand Region, India

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ABSTRACT
Study was conducted to determine environmental drivers for benthic macroinvertebrate assemblages and distribution patterns in a plateau river, the Dhasan. Four sampling stations (S1-S4) were selected from headwater to mouth. Lifting of stones and sieving of substratum methods were used to collect benthic macroinvertebrate fauna seasonally from December 2018 to November 2019. The collected samples were identified at the family level to determine assemblages and functional feeding groups. Canonical correspondence analysis (CCA) was used to determine important environmental drivers for invertebrate distribution. The richness of benthic macroinvertebrate fauna varied among the stations. Total mean density increased from S1 to S2, declined at S3 and again increased at S4. Thiaridae was found to be the most abundant taxa at all stations. The assemblages forming taxa varied among the station. Functionally, scrappers were the most dominant functional feeding groups at all the stations. Water temperature, land use, current velocity and dissolved oxygen were the important environmental drivers for invertebrate distribution.

Key words: Dhasan River, Ganga Basin, Scrapper, Thiaridae, Water temperature, CCA

INTRODUCTION

In the lotic ecosystem, benthic macroinvertebrates are an important component of aquatic communities, they have large distribution, being found in the sediment, in accumulated leaves, associates with macrophytes, between the rocks and therefore they interact with the environmental conditions (Moretti and Callisto 2005, Wurdig et al. 2007). In such a way, the benthic organisms are sensitive to the habitat characteristics and substratum (Buss et al. 2004), water temperature (Camargo and Voelz 1998), pH (Sandin and Johnson 2004), electric conductivity (Buss et al. 2002), sedimentation (Smith and Lamp 2008) and riparian vegetation (Silveira et al. 2006). This is one of the most threatened ecosystems (Ricciardi and Rasmussen 1999), because of climate change, landscape alteration, water quality and degradation of in-stream habitat (Sala et al. 2000).

The benthic macroinvertebrate communities showed different distributions in the space and time that vary in accordance with the morphology and physico-chemical conditions of water (Pereira and De Luca 2003, Silveira et al. 2006). The taxonomically related species often show contrasting distributional patterns and assemblage structure in relation to stream size (Edington and Hildrew 1995). The longitudinal changes in the relative contribution of allocthonous and autochthonous production are paralleled by changes in functional feeding group composition (Vannote et al. 1980, Grubaugh et al. 1996). Various studies were conducted in different parts of the Indian region like Himalaya (Singh et al. 1994, Nautiyal et al. 2015, Mishra and Semwal 2019, Negi and Singh 2021, Mishra and Dwivedi 2022), central India (Mishra and Nautiyal 2011, 2016, Nautiyal and Mishra 2013, Nautiyal et al. 2017, Pandey and Mishra 2021) and Western Ghat (Sivaramakrishnan et al. 1995, Subramaniam et al. 2005).

Bundelkhand is a geographic region of Central India and is divided between the states of Uttar Pradesh and Madhya Pradesh. This region is mainly known for low rainfall and dry region; thus, water scarcity is a major problem in this region. The rivers are the mainly useful for drinking as well as agriculture purposes by constructing barrage and dams for abstraction of river water. The river Dhasan is one of the Bundelkhand River having sever stress to meet out the agriculture and drinking purpose of the society and have barrage and dams. The present study is an attempt for determining of environmental drivers, assemblage structure and distributional patterns of benthic macroinvertebrate community of Dhasan rever.

MATERIAL AND METHODS

Study area

The river Dhasan is 365 km long, a moderate size southern sub-tributary of the river Yamuna in which it pours through the river Betwa. It originates at the northern skirt of Raisen district (Madhya Pradesh, India) and flow essentially northward to join the Betwa river near Jigni town of Uttar Pradesh. Four stations were selected on the Dhasan river based on land use and substrate patterns (Fig. 1, Table 1). Agriculture land use was mainly observed along the river length except mouth zone where forest land use prevails. The water abstraction point was situated as barrage/dam (Parichha dam) at lower zone.

Sampling

The benthic macroinvertebrate community was collected longitudinally from pre-selected stations (S1 to S4) in the summer, monsoon and winter seasons from December 2018 to November 2019. The physicochemical parameters like air, and water temperature (digital thermometer, Mextech 8 multimeter), transparency (Secchi disc), water current velocity (ENCON current meter), pH (model HI 96107), dissolved oxygen, nitrate and phosphate (Anonymous 1992) were measured at each station. The substrate predominance at each sampling station was estimated visually. If the river bed was extensively littered with cobble substrate followed by boulders and gravels, then substrate type was recorded as C: B: G. Substrate names and their categories were determined through Wentworth classification of substratum particle size (Wentworth 1922, Blott and Pye 2012).

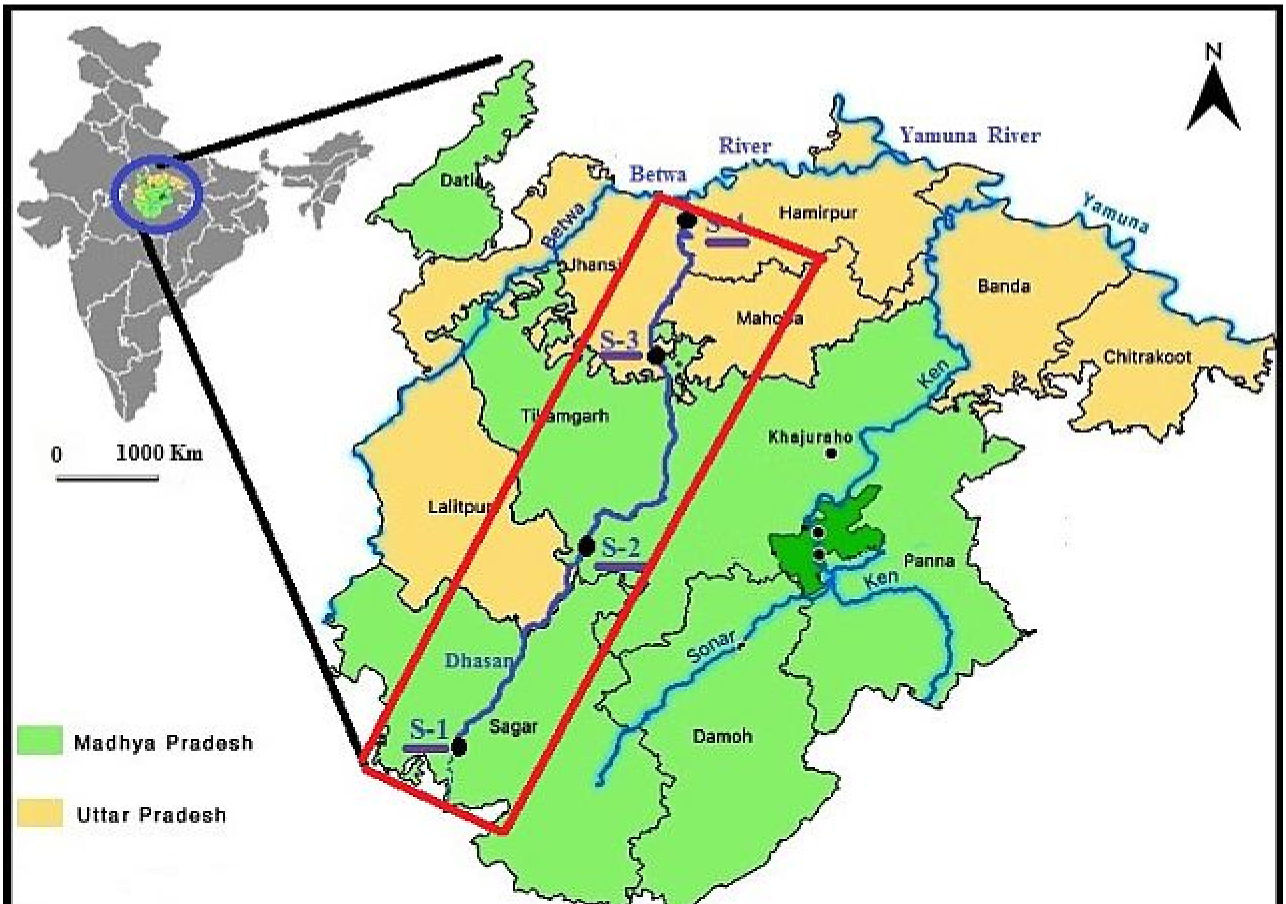

Figure 1. Location of Dhasan river in central highlands region. The blue line in the red colour rectangular frame indicates river Dhasan along with the location of sampling stations (S1 to S4)

Table 1. The physical characteristics of the river Dhasan at different stations (S1 to S4) in Central India. R- Rock, B- Boulder (<254 mm), C- Cobble (64 - 128 mm), P- Pebble (32 - 64 mm), G- Gravel (16 - 32 mm), S- Sand, Si- Silt, Cl- Clay, Ag- Agriculture, B/D- Barrage/Dam, F- Forest, DFS- Distance from source (Km), SD- Sampling depth. The substrate is more prismatic (sharp edges)

Parameter	**Johariya Sheikh (S1)**	**Badagaon (S2)**	**Devri /Deori Ghat (S3)**	**Jigani (S4)**
Latitude (°N)	23°47'49.5"	24°33'14.4"	25°13'58.9"	25°44'25.6"
Longitude (°E)	78°33'36.1"	79°02'24.7"	79°17'19.6"	79°23'41.9'
Altitude (m)	490	316	198	123
Land use	Ag	Ag	B/D	Ag+ F
River width (m)	28	170	400	200
SD (m)	0.18-0.65	30-180	30-50	15-45
DFS (km)	32	94	80	58
Substrate type	C>P>B> S	R>B>C>P	Cl>S>G>C>B	S>Si

The benthic macroinvertebrate fauna was collected by lifting stone method (stony substratum) and sieving substrate method (clay and silt bottom; mesh size 0.05 mm) from 30 cm² area. The samples were preserved in 5% formalin and identified to family level (Edmondson 1959, Edington and Hildrew 1995, Nesemann et al. 2004). The count seasonal data were computed to obtain annual trends for determining density, abundance assemblages (taxa >10%), and the functional feeding groups (Cotta Ramusino et al. 1995, Mishra and Nautiyal 2013b). The non-parametric text (Kruskal-Wallis test H-test) was used to determine the differences in densities among the stations (Henderson 2003). Canonical correspondence analysis (CCA) was applied on log-transformed data using Monte Carlo Permutation tests and forward selection to recognize the effective environmental variables impact on the taxonomic composition of benthic macroinvertebrate fauna in river Dhasan (ter Braak and Šmilauer 2002).

RESULTS

Physico-chemical characteristics

Annual mean water temperature as well as current velocity increased gradually from S1 (23.8±1.1°C, 23.9±4.5 cm s^{-1}) to S4 (26.9±0.9°C, 96.3±7.5 cm s^{-1}) as well as water transparency. Dissolved oxygen showed a continuous decline from station S1 (10.5±0.1 mg l^{-1}) to S4 (8.2±0.1 mg l^{-1}). While pH increased from S1 to S4, nitrate decreased from 0.7 mg l^{-1} at S1 to 0.6 mg l^{-1} at S2, then increased to 0.8 mg l^{-1} at S3 and finally declined to 0.6 mg l^{-1} at S4. However, phosphate values were found to be almost similar at all the stations (Table 2).

Benthic macroinvertebrate community features

The total number of benthic macroinvertebrate taxa (family) varied among the stations (14, 15, 15 and 14 respectively at S1, S2, S3 and S4) along the river length. Total mean density (individual m^{-2}) increased from S1 (273.2±31.85) to S2 (338.1±35.29), but declined at S3 (218.5±25.54) and again increase at S4 (308.4±17.42) (Table 2). Total density was significantly different among the stations ($p = 0.05$). Among the total benthic invertebrate fauna, Thiaridae was found to be most abundant taxa at all stations along the river length, with gradual increase from S1 (20.5%) to S4 (42.8%). However, the composition of other abundant (>5%) taxa (Caenidae, Baetidae, Viviparidae and Amblemidae) declined from S1 to S4, while Chironomidae, Gomphidae and Corbiculidae increased from S1 to S4 (Fig 2). The assemblages farming taxa (>10%) varied from S1 to S4 (Table 2).

Functional feeding group (FFG) characteristics

Functional feeding groups comprised scrapers (Sc), gathering collectors (GC), filtering collectors (FC) and predators (P). Scrapers were abundant FFGs at all the stations from S1 to S4 followed by gathering collectors > filtering collectors > predators. The composition of scrapers increased from headwater (S1, 36%) to lower section (S3, 47%), and slightly decreased at the mouth (S4, 45%). However, gathering collectors decreased from S1 to S2 and

Table 2. Mean (±) value of physico-chemical characteristics, benthic macroinvertebrate density and assemblages in the river Dhasan at various sampling stations. TH- Thiaridae, CE- Caenidae, VI- Viviparidae, CO- Corbiculidae, CH- Chironomidae

Parameter	**S1**	**S2**	**S3**	**S4**
Water temperature (^{o}C)	23.8±1.1	25.7±1.1	25.2±0.9	26.9±0.9
Current velocity (cm s^{-1})	23.9±4.5	63.8±6.5	47.3±5.2	96.3±7.5
Transparency (cm)	36.1±3.2	48.4±1.3	48.1±1.4	76.9±5.7
Dissolved Oxygen (mg l^{-1})	10.5±0.1	9.8±0.1	8.9±0.1	8.2±0.1
pH	7.5±0.1	7.2±0.1	7.4±0.0	8.0±0.0
Phosphate (mg l^{-1})	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0
Nitrate (mg l^{-1})	0.7±0.0	0.6±0.0	0.8±0.0	0.6±0.0
Density (Individual m^{-2}) *	273.2±31.85	338.1±35.29	218.5±25.54	308.4±17.42
Assemblages	TH-CE-VI-CO: 20.5-16.1-12.4 -12.4	TH-CE-CH-VI: 27.7-18.8-12-11.6	TH-CH-CO: 35.9-14.8-10.4	TH-CO-CH: 42.8-19.1-17.3

*Significant difference in density (H table value = 7.81< H observed value = 283.98)

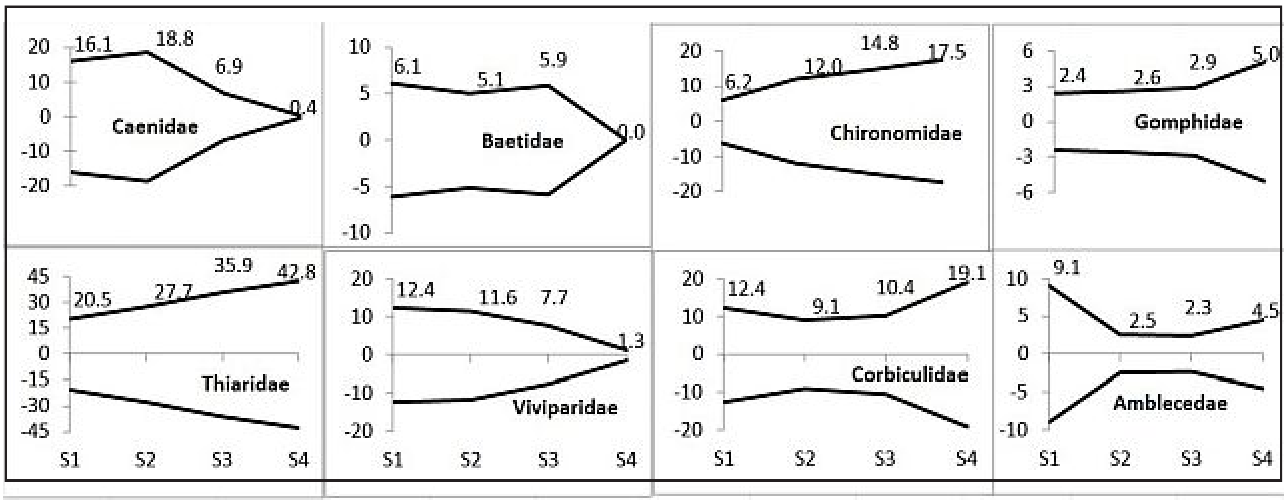

Figure 2. Longitudinal variation of abundant (5%) benthic macroinvertebrate fauna in the river Dhasan from sampling station S1 to S4

increased from S2 to S3 and S4. The filtering collectors and predators did not show any trend (Fig. 3).

Role of environmental drivers on benthic macroinvertebrate distribution

Canonical Correspondence Analysis (CCA) revealed that axis 1 and 2 explained 17.0 and 29.6% of cumulative variance in taxonomic composition and 35.6 and 62.1% of variation in taxon-environmental relationships. Water temperature (p-0.002, F-15.89) was observed as the most effective environmental driver for the distribution of Chironomidae and Gomphidae, while land use (p-0.002, F-9.62) and current velocity (p-0.002, F-8.77) were jointly responsible for those belonging to Thiaridae and Corbiculidae. Dissolved oxygen (p-0.002, F-8.73) was the effective environmental driver for the distribution of Amblemidae, Tabanidae and Elmidae (Table 3, Fig. 4).

DISCUSSION

Physico-chemical characteristics

Spatially, water temperature, current velocity, transparency and pH increases from S1 to S4, but reverse trend is evident for dissolved oxygen. The phosphate was observed to be similar among all the

Table 3. Taxon-environmental relationship and environmental drivers causing variation in the distribution of benthic macroinvertebrate fauna in river Dhasan. The important environmental drivers and their percentage impact on the distribution of benthic macroinvertebrate fauna.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.207	0.155	0.089	0.046	1.220
Species-environment correlations	0.866	0.890	0.819	0.684	
Cumulative (%) variance of taxon data	17.0	29.6	36.9	40.7	
Cumulative (%) variance of taxon-environment relation	35.6	62.1	77.4	85.3	
Sum of all eigenvalues					1.220
Sum of all canonical eigenvalues					0.582

Variable	Eigen values (λv)	% Variance explained = (λv) x 100/(λv)	P-value	F-value
WT	0.15	25.86	0.002	15.89
LU	0.08	13.79	0.002	9.62
CV	0.07	12.07	0.002	8.77
DO	0.06	10.34	0.002	8.73
SUB	0.05	8.62	0.002	6.34
SD	0.04	6.89	0.002	6.39
LAT	0.04	6.89	0.002	5.07
TRA	0.04	6.89	0.002	5.34
PO_4	0.03	5.17	0.002	5.79
NO_3	0.02	3.44	0.002	3.3

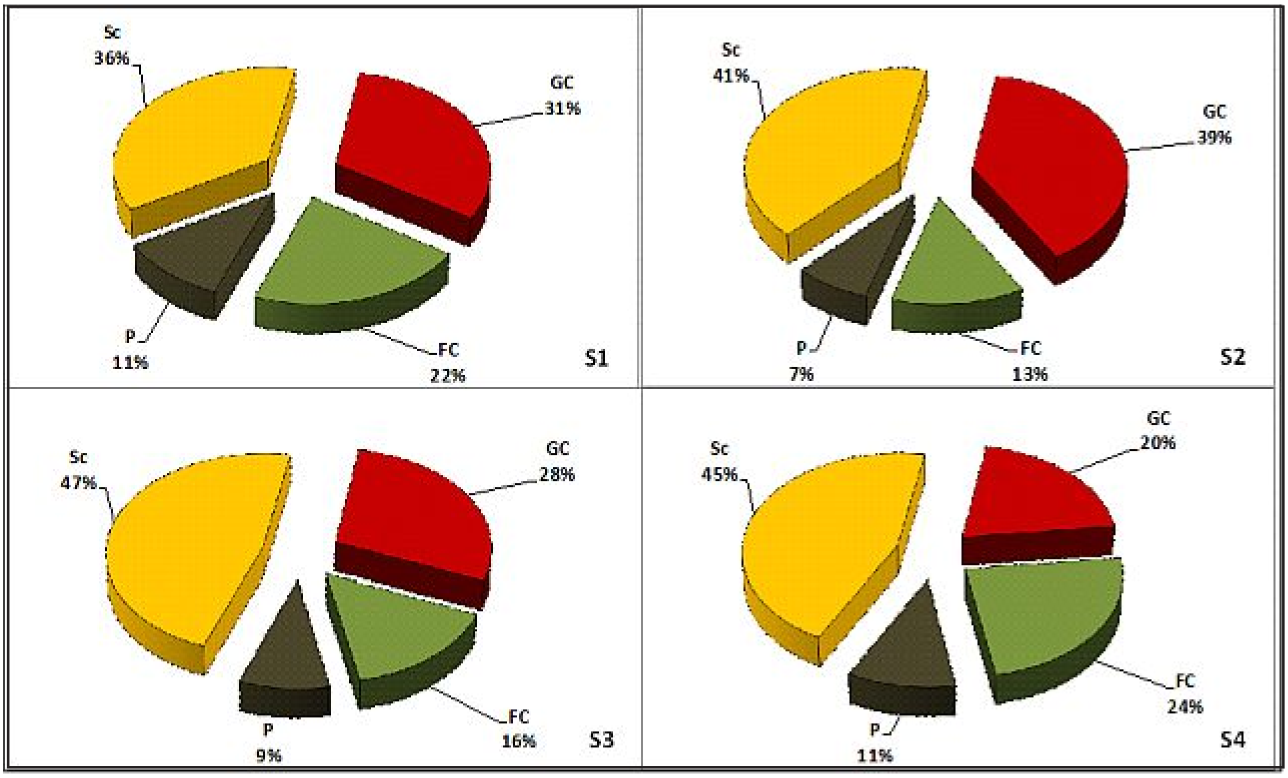

Figure 3. Composition of functional feeding groups of benthic macroinvertebrate fauna at various stations. (Sc- Scrapper, GC- Gathering Collector, FC- Filtering collector, P- Predator)

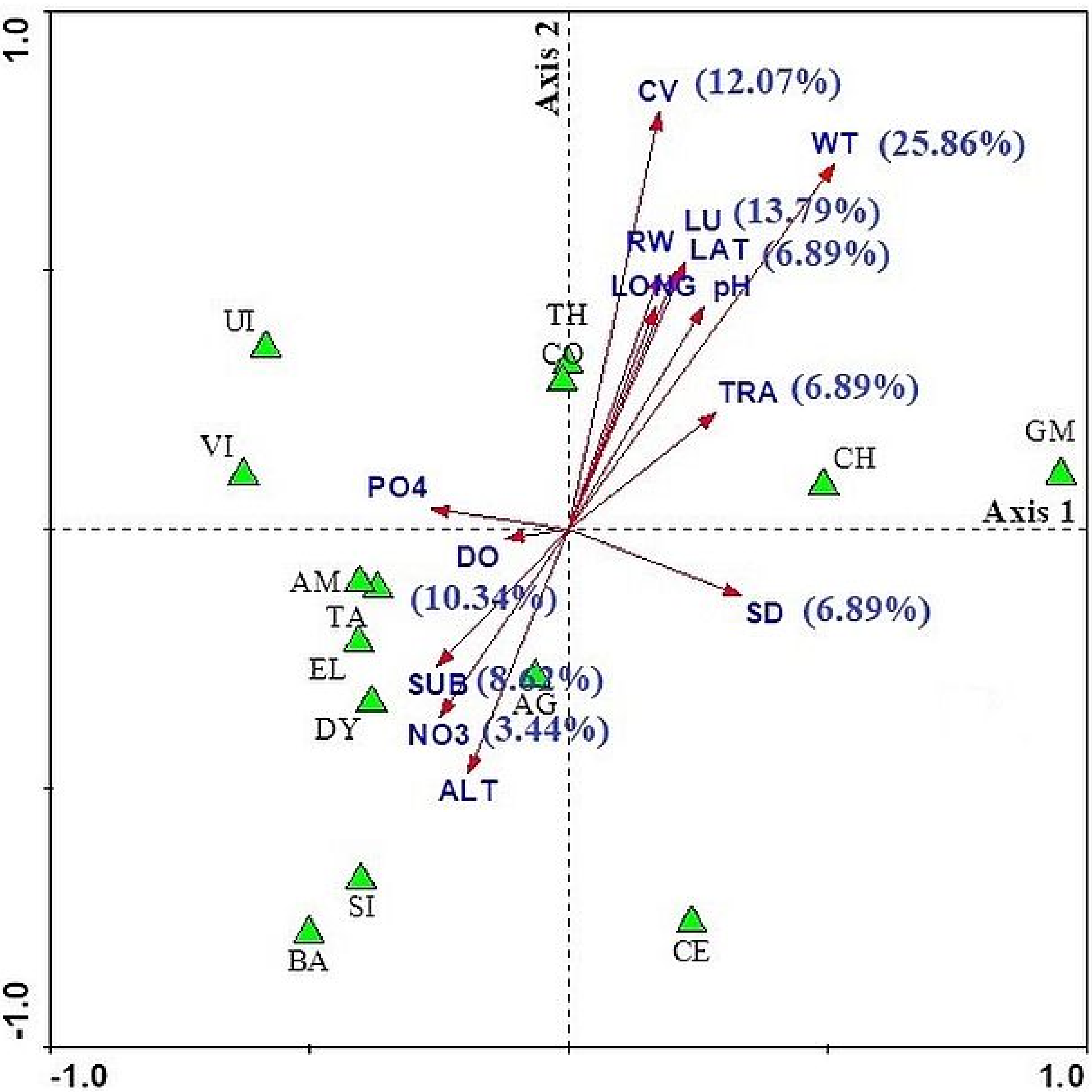

Figure 4. Canonical correspondence analysis (CCA) indicates relationship between environmental drivers and benthic macroinvertebrate fauna. Taxon and sampling locations are shown by arrows and triangle, respectively. The effective environmental variables are indicated in bold letters. (CV- Current velocity, LAT- Latitude, LONG- Longitude, ALT- Altitude, LU- Land use, RW- River width, SUB- Substratum, SD- Sampling depth, WT- Water temperature, TRA- Transparency, DO- Dissolved Oxygen, PO_4- Phosphate, NO_3- Nitrate, AM- Amblecidae, AG- Agrionidae, BA- Baetidae, CE- Caenidae, CH- Chironomidae, CO- Corbiculidae, DY- Dysticidae, EL- Elmidae, GM- Gomphidae, SI- Simulidae, TA- Tabanidae, TH- Thiaridae, UI- Unidentified, VI- Viviparidae

stations, while nitrate was initially declined from S1 to S2, and then increased to S3 and again declined at S4. High pH value was also observed at mouth section in the river Ken in central India (Nautiyal and Mishra 2012) and high-water temperature and velocity were observed in river Tons (Mishra and Nautiyal 2013a). Saksena et al. (2008) reported that range value of water temperature (17.6 - 33°C), pH (7.9 - 9.33), transparency (12.12 - 110 cm), dissolved oxygen (4.86 - 14.59 mg l^{-1}), phosphate (0.005 - 0.050

mg l^{-1}) and nitrate (0.008 - 0.025 mg l^{-1}) in the river Chambal. In the river Betwa, water temperature and pH ranged from 12.1 to 26.8^{O}C and from 6 to 7.1, respectively (Lakra et al. 2010).

Benthic macroinvertebrate community and functional feeding groups

Taxonomic richness increased from S1 to S2, but was found equal to S3 and declined to S4. This increase was attributed to the augment of substrate heterogeneity from S1 (Cobble > Pebble > Boulder) to S3 (Clay > Sand > Gravel > Cobble > Boulder) and less heterogeneous substrate (sand-silt > clay) at S4. The river Dhasan indicated a regular increase in density from S1 to S4, while an exceptional decline was recorded at S3. The sudden decline in density at S3 was attributed to barrage (Pahari Dam) for irrigation and drinking purposes. Substrate heterogeneity helps in increasing richness and density of benthic macroinvertebrate fauna in the rivers (Paul and Meyer 2001, Nautiyal and Mishra 2012, Mishra and Nautiyal 2016). Nautiyal and Mishra (2012) reported a decline of density due to abstraction of water for drinking and agriculture purpose in a central Indian river.

The increased abundance of most dominant taxa Thiaridae at downstream is attributed to increase of soft substratum and periphyton density. However, other taxa viz., Caenidae, Baetidae, Tabanidae, Viviparidae and Amblemidae declined from S1 to S4 because of reduction of substrate particle size and river channel. The reduction of substate particle helps increase of gathering collectors, scrapers and predators (Chironomidae, Thiaridae and Gomphidae). The Corbiculidae is functionally filtering collector and its abundance increases downstream towards mouth zone, which is attributed to abundance of ultrafine particulate organic matter. In other central highland rivers like Ken and Tons, collectors were reported abundant longitudinally downstream from headwater to mouth (Mishra and Nautiyal 2013b). However, Vannote et al. (1980) stated that a general reduction in detrital particle size occurs as the stream-size increases and collectors should increase in importance and dominate the macroinvertebrate assemblages of large streams.

Role of environmental drivers on benthic macroinvertebrate distribution

In the present study, the water temperature was the most effective environmental driver for the distribution of Chironomidae and Gomphidae, land use and current velocity were jointly responsible for Thiaridae and Corbiculidae. Similarly, dissolved oxygen most important variable for the distribution of Amblemidae, Tabanidae and Elmidae. In the Plateau streams, current velocity, water conductivity, substrate size and abundance of aquatic plants (Miserendino 2001). Substratum is found to be an important factor associated with the distribution of Thiaridae in the Bundelkhand streams Ken and Tons and water current velocity in Paisuni (Mishra and Nautiyal 2011, 2016). Nautiyal et al. (2017) indicated that land use, current velocity, and substratum are important variables for the distribution of benthic invertebrate fauna.

CONCLUSION

In the present study, the mean density of the benthic invertebrate fauna increases from headwater to mouth except at S3. The taxonomic richness also varied among the stations. The abundance of the dominant taxa (Thiaridae) increased downstream as the substrate particle size decreased toward the mouth section. The functional feeding status of the river tends to the autotrophic condition as the abundance of scrapers increases downstream. Water temperature, land use, current velocity, and dissolved oxygen were the important environmental drivers for the benthic macroinvertebrate fauna.

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REFERENCES

Anonymous. 1992. Standard Methods for Examination of Water and Wastewater. American Public Health Association, American Water Works Association, and Water Environment Federation, New York.

Blott, S.J. and Pye, K. 2012. Particle size scales and classification of sediment types based on particle size distributions: Review and recommended procedures. Sedimentology, 59(7), 2071-2096. https://doi.org/10.1111/j.1365-3091.2012.01335.x

Buss, D.F., Baptista, D.F., Silveira, M.P., Nessimian, J.L. and Dorville, L.F. 2002. Inuence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river basin in south-east Brazil. Hydrobiologia, 481, 125-136. https://doi.org/10.1023/A:1021281508709

Buss, D.F., Baptista, D.F., Nessimian, J.L. and Egler, M. 2004. Substrate specificity, environmental degradation and disturbance structuring macroinvertebrate assemblages in neotropical streams. Hydrobiologia, 518(1), 179-188. https://doi.org/10.1023/B:HYDR.0000025067.66126.1c

Camargo, J.A. and Voelz, N.J. 1998. Biotic and abiotic changes along the recovery gradient of two impounded rivers with different impoundment use. Environmental Monitoring Assessment, 50, 143-158. https://doi.org/10.1023/A:1005712024049

Cotta Ramusino, M., Villa, S. and Calamari, D. 1995. River continuum concept and correspondence analysis to study alpine stream macroinvertebrate community. Memorie dell'Istituto Italiano di Idrobiologia Dott Marco de Marchi, 53, 101-114.

Edington, J.M. and Hildrew, A.G. 1981. Caseless caddis larvae of the British Isles. Freshwater Biological Association, Ambleside, Cumbria. 91 pages. https://archive.org/details/keytocaselesscad0000edin/page/n1/mode/2up

Edmondson, W.T. 1959. Freshwater Biology. 2nd edition, John Wiley and Sons, INC, New York.

Grubaugh, J.W, Wallace, J.B. and Houston, ES. 1996. Longitudinal changes of macroinvertebrate communities along an Appalachian stream continuum. Canada Journal of Fish Aquatic Science, 53, 896-909. https://doi.org/10.1139/f95-247

Handerson, P.A. 2003. Practical Methods in Ecology. Blackwell scientific Publication, Oxford, London

Lakra, W.S., Sarkar, U.K., Kumar, R.S., Pandey, A., Dubey, V.K. and Gusain, O.P. 2010. Fish diversity, habitat ecology and their conservation and management issues of a tropical River in Ganga basin, India. Environmentalist, 30, 306-319. https://doi.org/10.1007/s10669-010-9277-6

Miserendino, M.L. 2001. Macroinvertebrate assemblages in Andean Patagonian rivers and streams: Environmental relationships. Hydrobiologia, 444, 147-148. https://doi.org/10.1023/A:1017519216789

Mishra, A.S. and Dwivedi, A.C. 2022. Taxonomic and trophic characterization of benthic macroinvertebrate fauna in headwaters of eastern Himalaya. Indian Journal of Ecology, 49(4), 1497-1502. https://doi.org/10.55362/IJE/2022/3689

Mishra, A.S. and Nautiyal, P. 2011. Factors governing longitudinal variation in benthic macroinvertebrate fauna of a small Vindhyan river in Central Highlands ecoregion (Central India). Tropical Ecology, 52(1), 103-112.

Mishra, A.S. and Nautiyal, P. 2013a. Longitudinal distribution of benthic macroinvertebrate assemblages in a Central Highlands River, the Tons (Central India). Proceedings of the National Academy of Science, India Section B Biological Science, 83(1), 47-51. https://doi.org/10.1007/s40011-012-0083-4

Mishra, A.S. and Nautiyal, P. 2013b. Functional composition of benthic macroinvertebrate fauna in the plateau rivers, Bundelkhand, central India. Journal of threatened taxa, 5 (13), 4752-4758. https://doi.org/10.11609/JoTT.o3226.4752-8

Mishra, A.S. and Nautiyal, P. 2016. Substratum as determining factor for the distribution of benthic macroinvertebrate fauna in a river ecosystem. Proceedings of the National Academy of Science, India Section B Biological Science, 86(3), 735-742. https://doi.org/10.1007/s40011-015-0520-2.

Mishra, A.S. and Semwal. V.P. 2019. Longitudinal distribution of benthic macroinvertebrate fauna in a lesser Himalayan stream, Uttarakhand. Journal of Nehru Gram Bharati University, 8(1), 1-12.

Moretti, M.S. and Callisto, M. 2005. Bio-monitoring of benthic macroinvertebrates in the middle Doce River watershed. Acta Limnologica Brasiliensia, 17(3), 267-281. http://labs.icb.ufmg.br/benthos/index_arquivos/pdfs_pagina/Moretti&Callisto2005.pdf

Nautiyal, P. and Mishra, A.S. 2012. Longitudinal distribution of benthic macroinvertebrate fauna in a Vindhyan river, India. International Journal of Environmental Science, 1(3), 150-158.

Nautiyal, P. and Mishra, A.S. 2013. Variations in benthic macro-invertebratefauna as indicator of land use in the Ken river, Central India. Journal of Threatened Taxa, 5(7), 4096-4105. https://doi.org/10.11609/JoTT.o3211. 4096-105

Nautiyal, P., Semwal, V.P. and Mishra, A.S. 2015. Spatial distribution of benthic macroinvertebrate fauna in mountain streams of Uttarakhand, India. pp. 31-51. In: Rawat, M., Dookia, S. and Sivaperuman, C. (Eds.). Aquatic Ecosystem: Biodiversity, Ecology and Conservation, Springer Publication, India. https://doi.org/10.1007/978-81-322-2178-4_4

Nautiyal, P., Mishra, A.S., Verma, J. and Agrawal, A. 2017. River ecosystems of the Central Highland ecoregion: Spatial distribution of benthic flora and fauna in the Plateau Rivers (tributaries of the Yamuna and Ganga) in Central India. Aquatic Ecosystem Health Management, 20(1-2), 43-58. https://doi.org/10.1080/14634988.2017.1296324

Negi, P. and Singh, S. 2021. Benthic macroinvertebrates diversity and quality of water in first-order streams of Badiyar Gad, lesser Himalaya, Uttarakhand, India. International Journal of Environmental Studies, https://doi.org/10.1080/00207233.2021.1992119

Nesemann, H., Sharma, G. and Sinha, R.K. 2004. Aquatic annelid (Polychaeta, Oligochaeta, Hirudinea) of the Ganga river and adjacent water bodies in Patna (India: Bihar), with description of new leech species (Family Salifidae). Annals of Natural History Museum Wien, 105 B, 139-187. https://www.jstor.org/stable/41767284

Pandey, C.K. and Mishra, A.S. 2021. Longitudinal patterns of benthic macroinvertebrate fauna in river Dhasan, Central India. Applied Biological Research¸ 23 (4), 331-340. https://doi.org/10.5958/0974-4517.2021.00043.4

Paul, M. and Meyer, J. 2001. Streams in the urban landscape. Annual Review Ecology, Evolution Systematics, **32,** 333-365. https://doi.org/10.1146/annurev.ecolsys.32.081501.114040

Pereira, D. and de Luca, S.J. 2003. Benthic macroinvertebrates and the quality of the hydric resources in Maratá Creek basin (Rio Grande do Sul, Brazil). Acta Limnologica Brasiliensia, 15(2), 57-68. http://hdl.handle.net/10183/249525

Ricciardi, A. and Rasmussen, J.B. 1999. Extinction rates of North American freshwater fauna. Conservation Biology, 13, 1220-1222. https://www.jstor.org/stable/2641755

Saksena, D.N., Garg, R.K. and Rao, R.J. 2008. Water quality and pollution status of Chambal river in National Chambal Sanctuary, Madhya Pradesh. Journal of Environmental Biology, 29(5), 701-710. https://jeb.co.in/journal_issues/200809_sep08/paper_10.pdf

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. and Wall, D.H. 2000. Global biodiversity scenarios for the year 2100. Science, 287, 1770-1774. https://doi.org/10.1126/science.287.5459.1770

Sandin, L. and Johnson, R.K. 2004. Local, landscape and regional factors structuring benthic macroinvertebrate assemblages in Swedish streams. Landscape Ecology, 19(5), 501-514. https://doi.org/10.1023/B: LAND.0000036116.44231.1c

Silveira, M.P., Buss, D.F., Nessimian, J.L. and Baptista, D.F. 2006. Spatial and temporal distribution of benthic macroinvertebrates in a South eastern Brazilian river. Brazilian Journal of Biology, 66(2B), 623-632. https://doi.org/10.1590/S1519-69842006000400006

Singh, H.R., Nautiyal, P., Dobriyal, A.K., Pokhriyal, R.C., Negi, M., Baduni, V., Nautiyal, R., Agarwal, N.K., Nautiyal, P. and Gautam, A.I. 1994. Water quality of the river Ganga (Garhwal-Himalaya). Acta Hydrobiologia, 34(1), 3-15.

Sivaramakrishnan, K.G., Venkataraman, K., Sridhar, S. and Marimuthu, U. 1995. Spatial patterns of benthic macroinvertebrate distribution along river Kaveri and its tributaries (India). International Journal of Ecology and Environmental Science 21, 141-161.

Smith, R.F. and Lamp, W.O. 2008. Comparison of insect communities between adjacent headwater and main-stem streams in urban and rural watersheds. Journal of North American Benthological Society, 27(1), 161-175. https://doi.org/10.1899/07-071.1

Subramanian, K.A., Sivaramakrishnan, K.G. and Gadgil, M. 2005. Impact of riparian land use on stream insects of Kudremukh National Park, Karnataka state, India. Journal of Insect Science, 5(49),1-10. https://doi.org/10.1093/jis/5.1.49

ter Braak, C.J.F, Šmilauer, P. 2002. CANOCO Reference Manual and Cano Draw for Windows User's Guide: Software for Canonical Assemblage Ordination (version 4.5). Microcomputer Power, Ithaca, NY, USA.

Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R. and Cushing, C.E. 1980. The river continuum concept. Canada Journal of Fish Aquatic Science, 37, 130-137. https://doi.org/10.1139/f80-017

Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. Journal of Geology, 30, 377-392. https://doi.org/10.1086/622910

Wurdig, N.L., Cenzano, C.S.S. and Motta, D.M. 2007. Macroinvertebrate communities' structures in different environments of the Taim Hydrological System in the state of Rio Grande do Sul, Brazil. Acta Limnologica Brasiliensia, 19(4), 57-68. https://app.periodikos.com.br/article/627b11f5782aad05cf54924e/pdf/alb-19-4-427.pdf

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